

2006

Effects of terraces on submerged aquatic vegetation in shallow marsh ponds in coastal southwest Louisiana

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EFFECTS OF TERRACES ON SUBMERGED AQUATIC VEGETATION IN
SHALLOW MARSH PONDS IN COASTAL SOUTHWEST LOUISIANA

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College

In partial fulfillment of the
Requirements for the degree of
Master of Science

in

The School of Renewable Natural Resources

Christopher Dean Cannaday
B.S. Louisiana Tech University 1998
August, 2006

ACKNOWLEDGEMENTS

This project was funded by the Louisiana Department of Wildlife and Fisheries. The staff of Rockefeller State Wildlife Refuge and Sabine National Wildlife Refuge provided logistical support and valuable advice. They also provided a place to stay and a ride out of the marsh when we broke down for which I am even more grateful. I thank Rockefeller State Wildlife Refuge, Sabine National Wildlife Refuge, Seth Bordelon, Aaron Caldwell, Kendall Decoteau, Bryan Gossman, Christina Legleu, Nick Mayer, George Melancon, Melissa Miller, Jessica O'Connell, Steven Olivier, and Steve Reagan for their help with fieldwork.

I would like to thank the members of my graduate committee; my major professor Dr. J. Andrew Nyman for his support, guidance, advice, and patience, Dr. Megan La Peyre and Dr. Frank Rohwer for honest and informative input on my thesis research. I also want to thank the many members of the Experimental Statistics Department who answered a myriad of questions with great patience, especially Dr. Jing Wang, Dr. Barry Moser, and Dr. David Blouin.

Finally, I thank my parents, Dean and Shirley Cannaday, for their constant support and encouragement. But most of all I would like to thank my wife Kelli Cannaday, for her love, patience, and understanding.

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ABSTRACT

The wetlands of coastal Louisiana are disappearing at a rate of 65 to 80 km²yr⁻¹. Most of the loss is the conversion of emergent marsh to shallow marsh ponds. Terracing is one restoration technique that has been used frequently in recent years. Terraces are small intertidal ridges built in shallow marsh ponds to reduce wave action. It is assumed that this will slow erosion of adjacent emergent marsh and increase Submerged Aquatic Vegetation (SAV) production, a key habitat component for many marsh fauna. Yet both relevant previous studies failed to show that terraces increased SAV abundance. In April of 2004 this study was initiated to test this assumption. Three study sites with paired terraced and unterraced ponds were selected in southwest Louisiana; two at Rockefeller State Wildlife Refuge and one at Sabine National Wildlife Refuge. SAV abundance was estimated every other month for one year. SAV biomass and frequency were significantly higher in terraced ponds. SAV frequency in unterraced ponds averaged 20% (SE 13 to 33%) but frequency for unterraced ponds was 9% (SE 5 to 14%). Terraced ponds had approximately three and half times the biomass of unterraced ponds. This indicates that terraces improve SAV production as had been suspected. Turbidity and organic matter content were lower in terraced ponds indicating a possible causal mechanism. My results confirm some assumptions of wetland restoration planners who have used terraces.

INTRODUCTION

Louisiana coastal wetlands stretch from Texas to Mississippi and inland for over twenty miles. These wetlands make up approximately 40% of the nation's coastal wetlands, but have experienced 80% of losses since the 1930's (Boesch et al. 1994). Unlike other parts of the country, most of these losses have not resulted from development. Instead, most of the marsh loss in Louisiana results from conversion of emergent marsh to shallow ponds (Sasser et al. 1986, Leibowitz and Hill 1987, Turner and Rao 1990). Several natural factors, including subsidence, sea-level rise, erosion (Boesch et al 1994) and processes associated with the delta lobe cycle (Coleman 1988) are partially responsible. Various anthropogenic changes such as levees, canals, diversions, and dredging also contribute to the loss (Boesch et al. 1994).

In 1989, the Louisiana legislature created a state coastal wetland restoration program and the Wetlands Conservation and Restoration Fund, commonly referred to as the Wetlands Trust Fund (CWPPRA 2003) to restore and protect coastal wetlands. This was followed in 1990 by the creation of the federal Coastal Wetland Planning, Protection Restoration Act (Public Law 101-646, Title III—CWPPRA) by the U.S. Congress. This act created funding for coastal restoration and protection. Nongovernmental Organizations, such as Ducks Unlimited, and state agencies, such as the Louisiana Department of Wildlife and Fisheries are also funding restoration in the coastal marshes. Other restoration projects are the result of mitigation to replace wetlands lost to development. Together, these funding sources support the construction of various projects to conserve and restore wetlands in Louisiana.

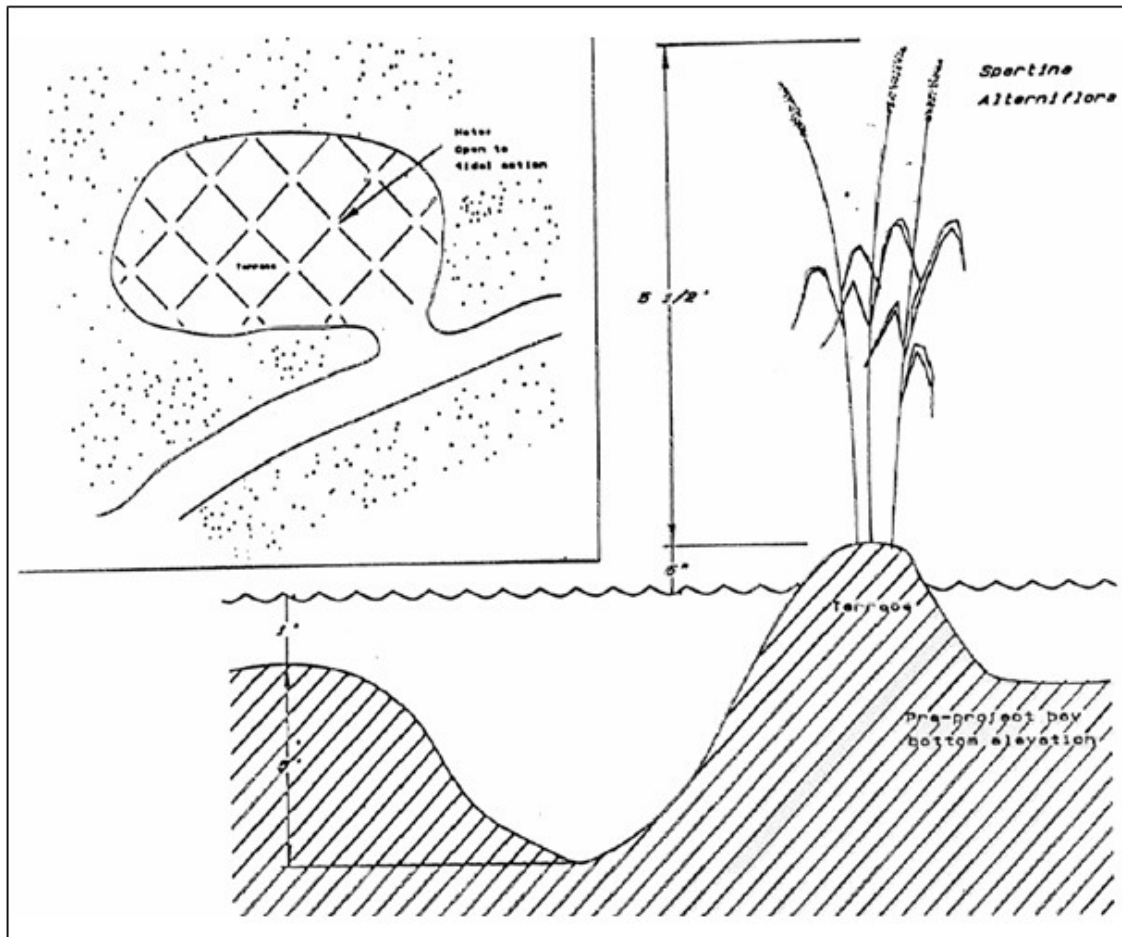
Restoration in Louisiana usually focuses on using various methods to introduce freshwater and sediment from rivers because much of the marsh loss results from a lack of sediment input. But in many places, especially southwest Louisiana, marshes are too far from rivers for these methods to be feasible. Terraces are a relatively new technique that was developed to address this issue in the late 1980's (Steyer 1993). Terracing has been used frequently in recent years (Table 1).

Terraces are small ridges built within shallow tidal ponds to reduce wave action, prevent erosion, and enhance marsh interspersion (Fig. 1) (Steyer 1993, Boesch 1994). Generally, they are constructed using local sediment from the bottom of the ponds. They are designed to be inundated during normal high tide (i.e. the same elevation as the surrounding marsh). Arrangements differ, but most are perpendicular to the prevailing winds of the area. The ridges are not continuous; they have openings to allow water flow and ingress and egress of marine organisms (Steyer 1993). The tops of terraces are vegetated with marsh grasses such as *Spartina alterniflora* (Ait.) Muhl. to prevent erosion and enhance marsh interspersion (Fig. 1).

Terraces create a small amount of emergent marsh and increase the amount of marsh interface (Steyer 1993). They also increase nekton abundance (Rozas et al. 2001, Bush et al. 2003, Gossman 2005). Terraces are assumed to increase the abundance of submerged aquatic vegetation (SAV) and reduce erosion of adjacent marsh (Underwood et al. 1991) by reducing wave fetch and turbidity. The assumed effect on SAV is based on research that shows SAV growth and distribution is significantly affected by turbidity (Livingston et al. 1998, Onuff 1994) and wave fetch (Koch 2001). 1

Table 1. Wetland restoration and mitigation projects in Louisiana where terraces were built or planned

Project Name	Marsh type	Length of Terraces (m)
...CWPPRA Restoration Projects...		
LaBranche Wetlands Terracing, Plantings, and (PO-28)	intermediate	21,330
Little Vermilion Bay Sediment Trapping (TE-12)	fresh	7,110
Sweet Lake/Willow Lake Shoreline Protection (C/S-11b)	fresh	23,360
Plowed Terrace Demonstration Project (C/S-25)	intermediate	16,450
Brown Lake Hydrologic Restoration (C/S-09)	brackish	7,630
East Sabine Lake Hydrologic Restoration (C/S-32)	brackish	undecided
Four Mile Canal Terracing and Sediment ... (TV-18)	fresh	19,500
Pecan Island Terracing (ME-14)	brackish	60,890
Sabine Terraces (C/S-ST)	brackish	undecided
Sediment Trapping at the Jaws (TV-15)	fresh	18,600
...Coastal Impact Assistance Program Projects...		
Oyster Lake Terracing, Marsh Island Refuge	brackish	4,430
...Mitigation Projects of which I am aware...		
Cameron Creole NWR,	brackish	unknown
Rockefeller State Wildlife Refuge, Unit 4	brackish	unknown
Rockefeller State Wildlife Refuge, Unit 5	brackish	unknown
Sabine NWR, Unit 6	brackish	16,000
Sabine NWR, Unit 7	brackish	6,020
Sweet Lake	brackish	unknown



SAV is important to waterfowl, fish, and invertebrates as habitat and as food (Stutzenbaker 1999, Castellanos and Rozas 2001, Kanouse 2003). A number of factors affect SAV, including water temperature, salinity, soil nutrient content, water nutrient content, herbivory, desiccation, wave fetch, organic matter, turbidity, water depth and competition (Anderson 1986, Onuf 1994, Koch 2001, Merino 2005).

The Wetland Value Assessment (WVA), which is used by agencies in Louisiana to rank restoration alternatives, ranks aquatic vegetation as the second most important variable in computation of its habitat suitability index (EWG 1998). For this reason, and because of their relatively low costs, projects that incorporate terraces (theoretically increasing SAV) in their restoration plans often rank higher than other restoration projects (J. Nyman personal observation).

However, there are few data to support the assumed increase in SAV abundance with terracing. Steyer (1993) found that, of the three species planted near terraces in his study, only *Halodule beaudettei* den Hartog. had any significant survival. *H. beaudettei* had survival rates twice as high in an unterraced control pond as in two terraced ponds. Caldwell (2003) concluded that terraces did not increase SAV abundance above that found in open water.

Steyer (1993) and Caldwell (2003) are the only two studies to quantify the effects of terraces on SAV. Neither study supports the assumption that terraces increase SAV abundance, yet both studies had limitations that lessen their applicability to other sites.

First, the natural pond in Steyer's (1993) study was deeper than the two terraced ponds and was further from Calcasieu Lake, which was a source of turbidity. In addition, the SAV in the terraced ponds in Steyer's study was also exposed on mudflats

occasionally while the control, SAV in the unterraced pond, was not (Steyer 1993). This could also explain the poorer survival of SAV in the terraced ponds, because desiccation negatively impacts vascular SAV (Harwell 2003). Also, the ponds used in Steyer's (1993) study were located in salt marsh. Few terraces have been built in salt marshes since then, further reducing its applicability to today's restoration efforts.

Perhaps the most limiting factor of Steyer's study is that SAV was only sampled once, two months after planting, in August of 1991. It is unlikely that sediments disturbed during terrace construction had settled by that time (Onuf 1994). So it is possible that higher turbidity in the terraced ponds lowered SAV survival (Steyer 1993). Sampling only once for SAV is impractical for other reasons as well. SAV abundance depends on a variety of environmental factors that can change over the course of days, weeks, or months (Koch 2001, Merino 2005). For example, *Ruppia maritima* L. (Widgeon grass), can act as an annual or perennial depending on water temperature, salinity, and a variety of other factors (Kantrud 1991). So Steyer's (1993) study could have sampled when SAV was not abundant because of factors unrelated to terraces.

In Caldwell's (2003) study, even though SAV frequency near natural marsh was significantly higher than near terraces, this effect was only seen once out of 5 sampling periods. SAV abundance was extremely low in the other four sampling periods for all habitat types (Caldwell 2003). In addition, the Caldwell (2003) study was limited to one pond.

These two studies were both confined to a single terrace project. From a restoration perspective, the lack of replication is important because it limits their applicability. Wave fetch, turbidity, and other factors vary widely. Consequently, the

amount, distribution, and species of SAV also vary widely. Single site studies also do not take into account the effects that different terrace designs may have on SAV. The goal of this study was to incorporate multiple study sites in brackish marsh in one study to test the null hypothesis that there is no difference in SAV abundance between terrace SAV samples and untterraced SAV samples. I sampled every other month for one year to account for SAV variability over time. I chose sites within brackish marshes because today most terraces are built in brackish marsh.

STUDY AREA

My study was conducted in three sets of terraced ponds (experimental) and unterraced ponds (control) in marsh dominated by *Spartina patens* (Ait.) Muhl. (Marshhay cordgrass) an indicator of brackish marsh. Each pair was hydrologically unique and separate from the other study areas. Two pairs of ponds were located on the Rockefeller State Wildlife Refuge and one pair was found on the Sabine National Wildlife Refuge (Fig. 2). Rockefeller State Wildlife Refuge is near Grand Chenier, Louisiana on the Gulf Coast, 49 miles south southeast of Lake Charles. Sabine National Wildlife Refuge is south of Hackberry, Louisiana on the east side of the Sabine River and Sabine Lake and north of state highway 82.

Site Selection

Four criteria were used for site selection. The first criterion was location within *S. patens* dominated marsh. The second criterion was that the terraces had to be at least twelve months old. This age criterion was to ensure that sediments disturbed by construction had time to settle (Onuff 1994). As a further criterion for selection, only terraced ponds that had nearby unterraced ponds with similar size and hydrology. In addition, sites for this study were limited to areas where we were able to obtain permission to study. Other sites that were available but were not used for various reasons include: Black Bayou, Cameron Prairie, Sweet Lake, and Pecan Island.

Site 1

One site was located in management Unit 4 of Rockefeller State Wildlife Refuge (Fig. 3). The management unit contained a brackish marsh that was hydrologically isolated by a levee and water control structures (Fig. 4).

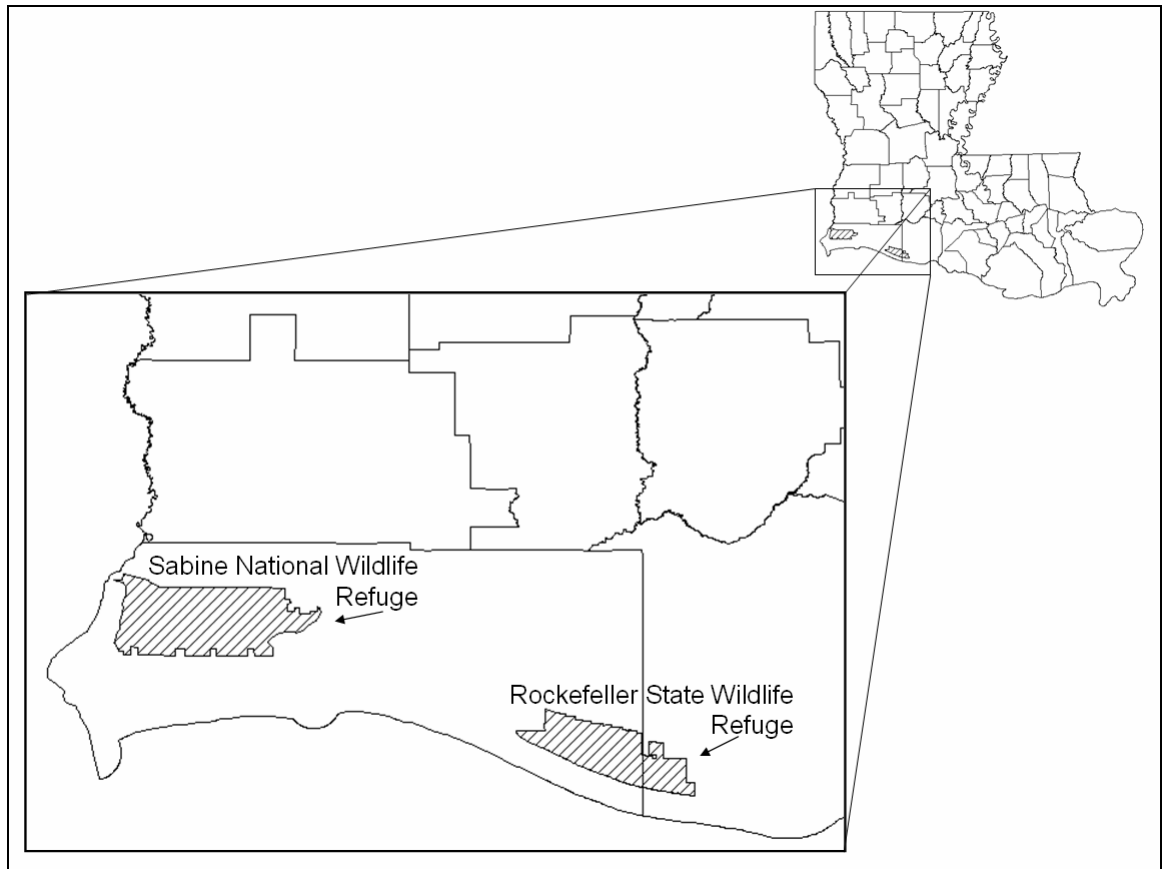


Figure 2. Vicinity Map of Study

Emergent vegetation consisted primarily of *S. patens*, with *Scirpus robustus* Pursh, syn. *Scirpus maritimus* L. (Saltmarsh bulrush), *Spartina alterniflora* (Smooth cordgrass), *Scirpus californicus* (C.A. Meyer) Steud. (California bulrush), and various *Cyperus* species intermixed. *Phragmites australis* (Cav.) Trin ex Steud., syn. *Phragmites communis* Trin., (Roseau cane), formed dense stands in several areas. Common SAV were *Ruppia maritima*, *Potamogeton pusilus* L. (Thin-leaf pondweed), and *Myriophyllum spicatum* L. (Eurasian water-milfoil) with some *Ceratophyllum demersum* L. (Coontail) intermixed. Chlorophyta (Filamentous algae) were common at times. *R. maritima* was the most common SAV but was not always present. *R. maritima* may have been functioning as an annual with two growing seasons at this site, as other studies have suggested (Joanen and Glasgow 1965). SAV and emergent vegetation were both indicative of brackish marsh (Chabreck 1970, Chabreck 1971).

The terraced pond was in the northwest region of the management unit (UTM 1984, Zone 15N, coordinates: 0523597 East and 3284941 North), and the control pond was located south of the terraced pond (UTM 1984, Zone 15N, coordinates: 0523706 East and 3283839 North). The terraced pond was approximately 32,348 ha and the portion of the untterraced pond used was approximately 65,462 ha. The terraces were constructed in August of 2002 (personal communication, Melancon 2005).

Site 2

Another site was in management Unit 5 of Rockefeller Wildlife Refuge (Fig. 5). The management unit contained a brackish marsh that was surrounded by a levee with water control structures on three sides and separated from the gulf on the south by a natural, low beach rim (Fig. 6).

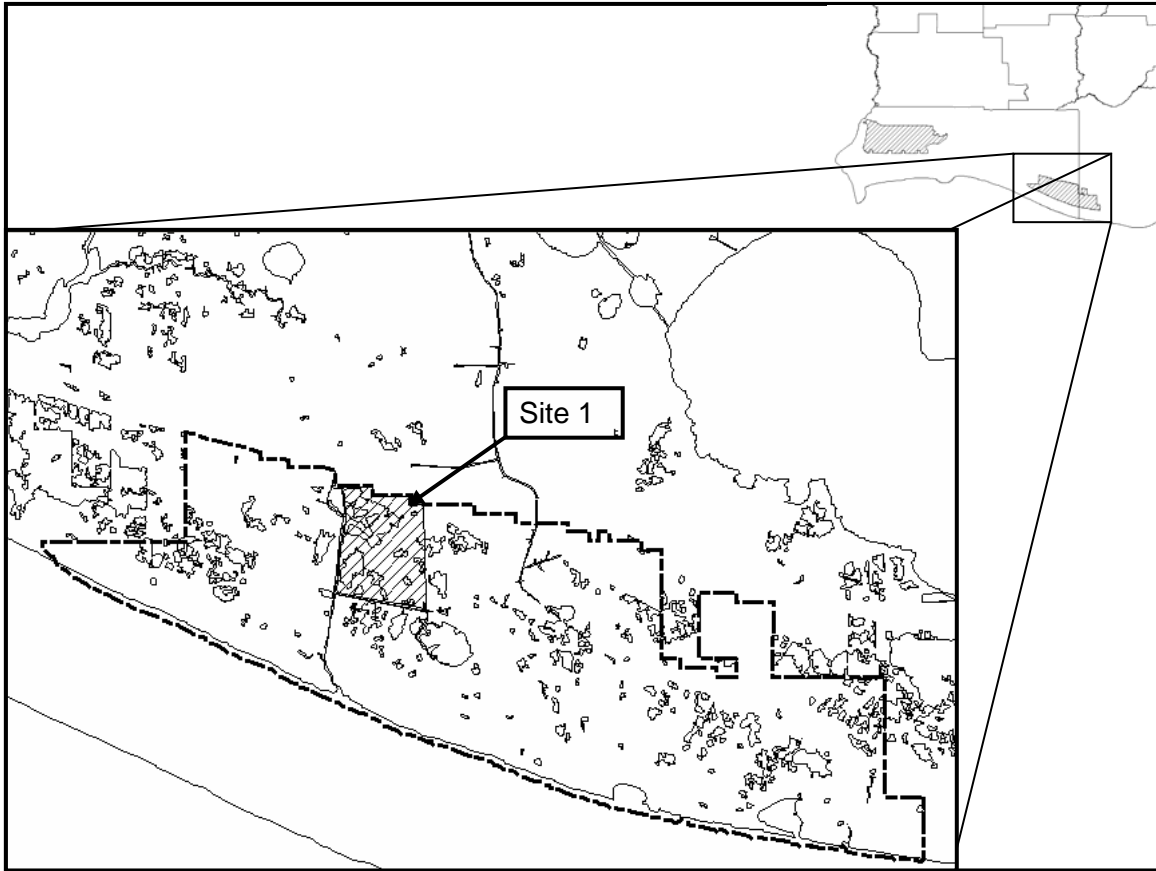


Figure 3. Site 1, Rockefeller Wildlife Refuge, Marsh Management Unit 4

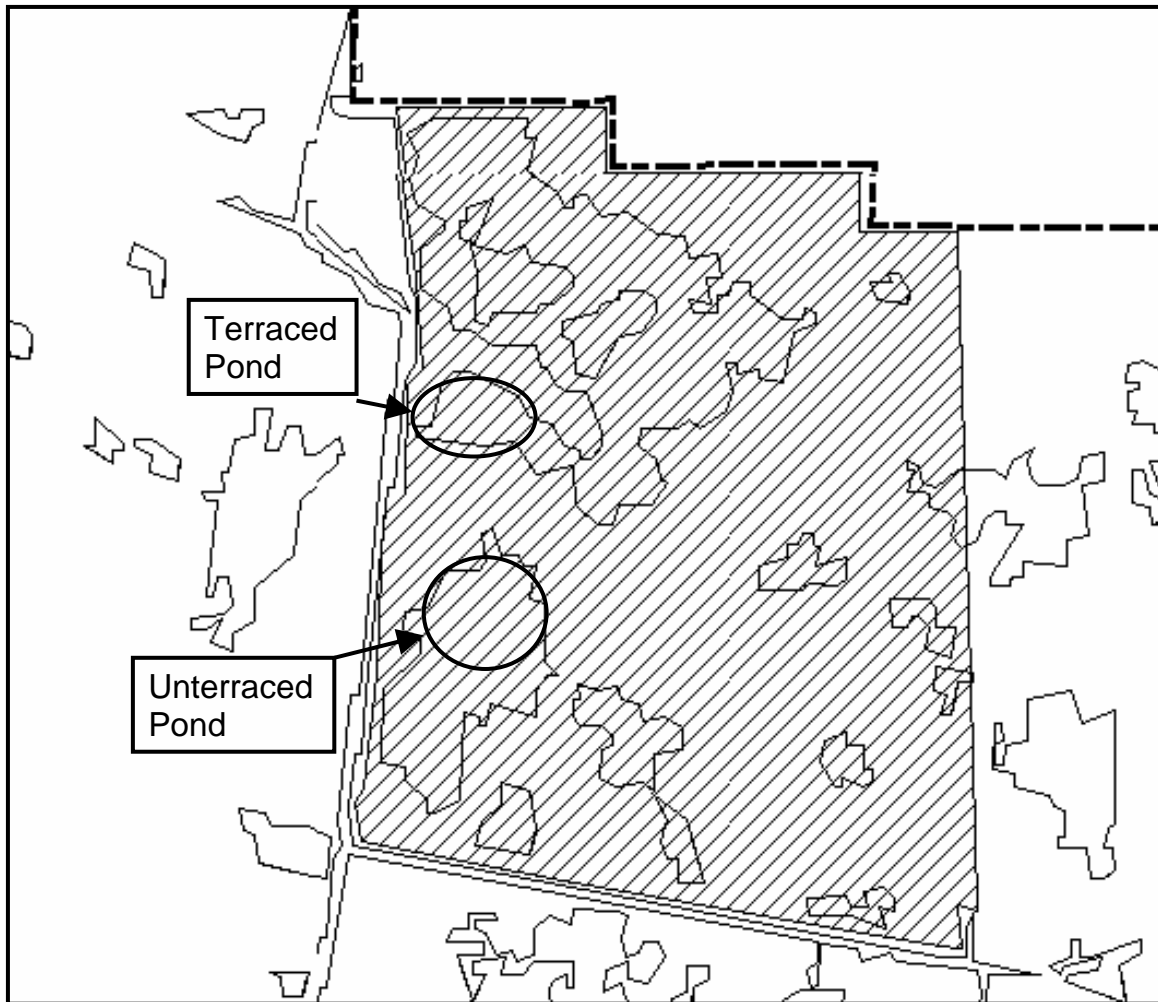


Figure 4. Site 1, Rockefeller State Wildlife Refuge, Management Unit 4, Terraced and Unterraced Pond Pair

Emergent vegetation at Site 2 consisted primarily of *S. patens* with *S. robustus*, *S. alterniflora*, *S. californicus* and various *Cyperus* species intermixed. *Phragmites australis* was also present but was not abundant. Common SAV in the unit were *Ruppia maritima*, *Potamogeton pusilus*, and filamentous algae. *R. maritima* was the most common SAV but was not always present. *R. maritima* may have been functioning as an annual with two growing seasons at this site, as other studies have suggested (Joanen and Glasgow 1965). SAV and emergent vegetation were both indicative of brackish marsh (Chabreck 1970, Chabreck 1971).

The terraced pond was in the north central portion of the management unit (UTM 1984, Zone 15N, coordinates: 0525399 East and 3280830 North) and the control pond (UTM 1984, Zone 15N, coordinates: 0524183 East and 3281185 North) was west of the terraced pond. The terraces were constructed in June of 2000 (personal communication, Melancon 2005). The terraced pond was approximately 58,791 ha and the portion of the unterraced pond used was approximately 50,749 ha.

The terraces of site 2 were in good condition when it was selected for the study in August of 2003. Unfortunately, by the time the study started in April 2004 the terraces had begun to deteriorate. In June 2005 they had deteriorated considerably and by April 2005 only one terrace still had emergent vegetation and only a few strips less than a meter in length remained of the other terraces. However, I retained Site 2 for my analysis for two reasons. First, I assumed that the terrace ridges could still be having an effect on wave action without vegetation. Second, I also concluded that including Site 2 in my analysis would make detecting a terrace effect on SAV more difficult- making all tests for differences between terraced and unterraced ponds more conservative.



Figure 5. Site 2, Rockefeller State Wildlife Refuge, Management Unit 5

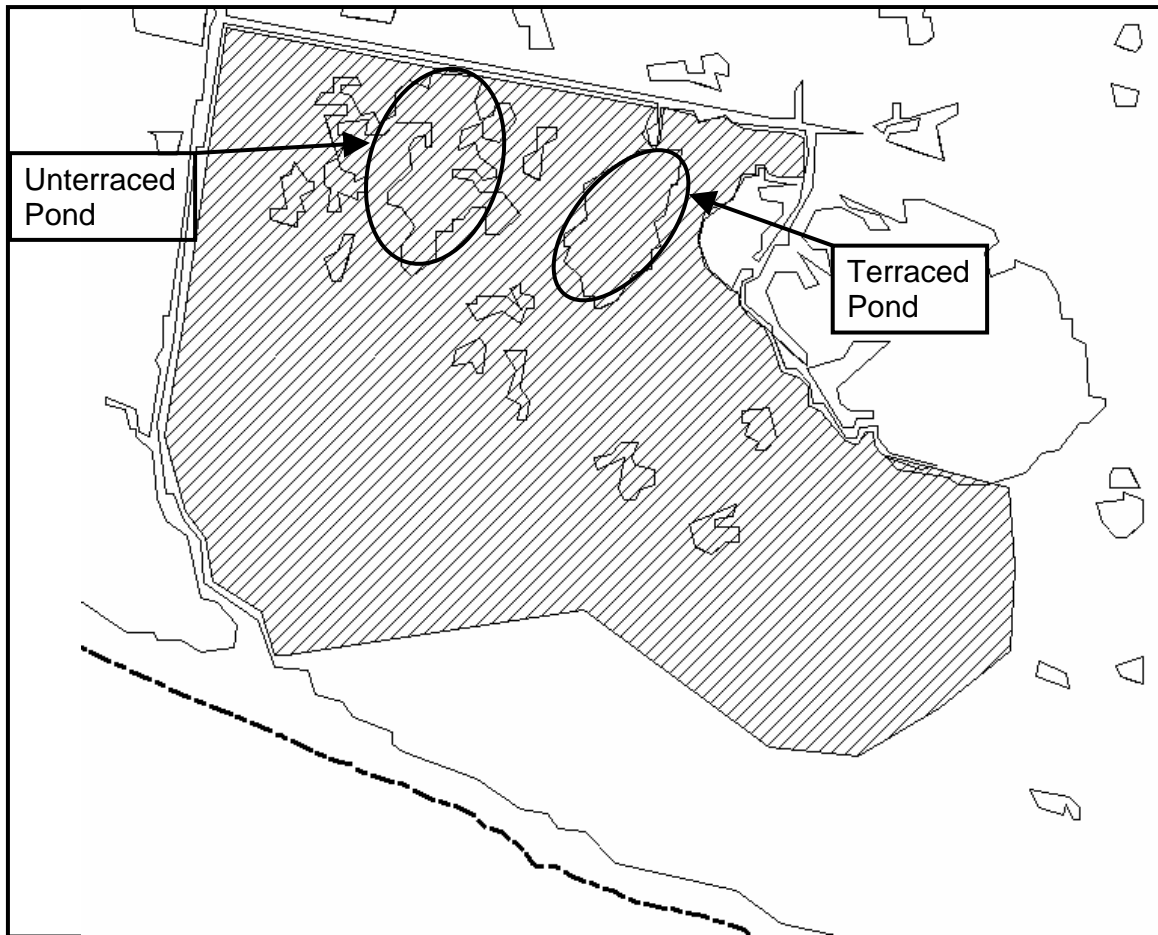


Figure 6. Site 2, Rockefeller State Wildlife Refuge, Wildlife Management Unit 4, Terraced and Unterraced Pond Pair

Site 3

One site was in Units 5 and 6 of Sabine National Wildlife Refuge (Fig. 7). The terraced pond was in Unit 6 and the untterraced pond was in Unit 5 (Fig. 8). The ponds were approximately 5.5 km from each other. The units were not separated by levees, and had similar physical characteristics.

Major emergent species in both units were *P. australis*, *S. americanus* Pers., Syn. *Scirpus olneyi* E. and G., (Olney three-square), *S. patens*, and *S. alterniflora*. Various *Cyperus* species, *Cladium jamaicense* Crantz. (Sawgrass), and *S. californicus*, were present in small patches. Common SAV in the unit were *M. spicatum*, *Najas guadalupensis*, (Spreng.) Magnus, *Chara* spp., *Nitella* spp., and filamentous algae. *Myriophyllum spicatum* was the most common SAV and was always present in the terraced pond. *Myriophyllum spicatum* was probably functioning as a perennial at this site. SAV and emergent vegetation were both indicative of brackish marsh (Chabreck 1970, Chabreck 1971).

The terraces were constructed in 2001. The terraced pond was in the north east portion of management unit 6 (UTM 1984, Zone 15N, coordinates: 0434212 East and 3304478 North) and the control pond (UTM 1984, Zone 15N, coordinates: 0434609 East and 3311970 North) was in the north end of Unit 5. The area of the terraced pond was approximately 482,016 ha and the area of the untterraced pond was approximately 1,259,785 ha. Shortly after I completed field sampling, construction began on terraces in the untterraced pond.



Figure 7. Site 3, Sabine National Wildlife Refuge, Management Units 5 and 6

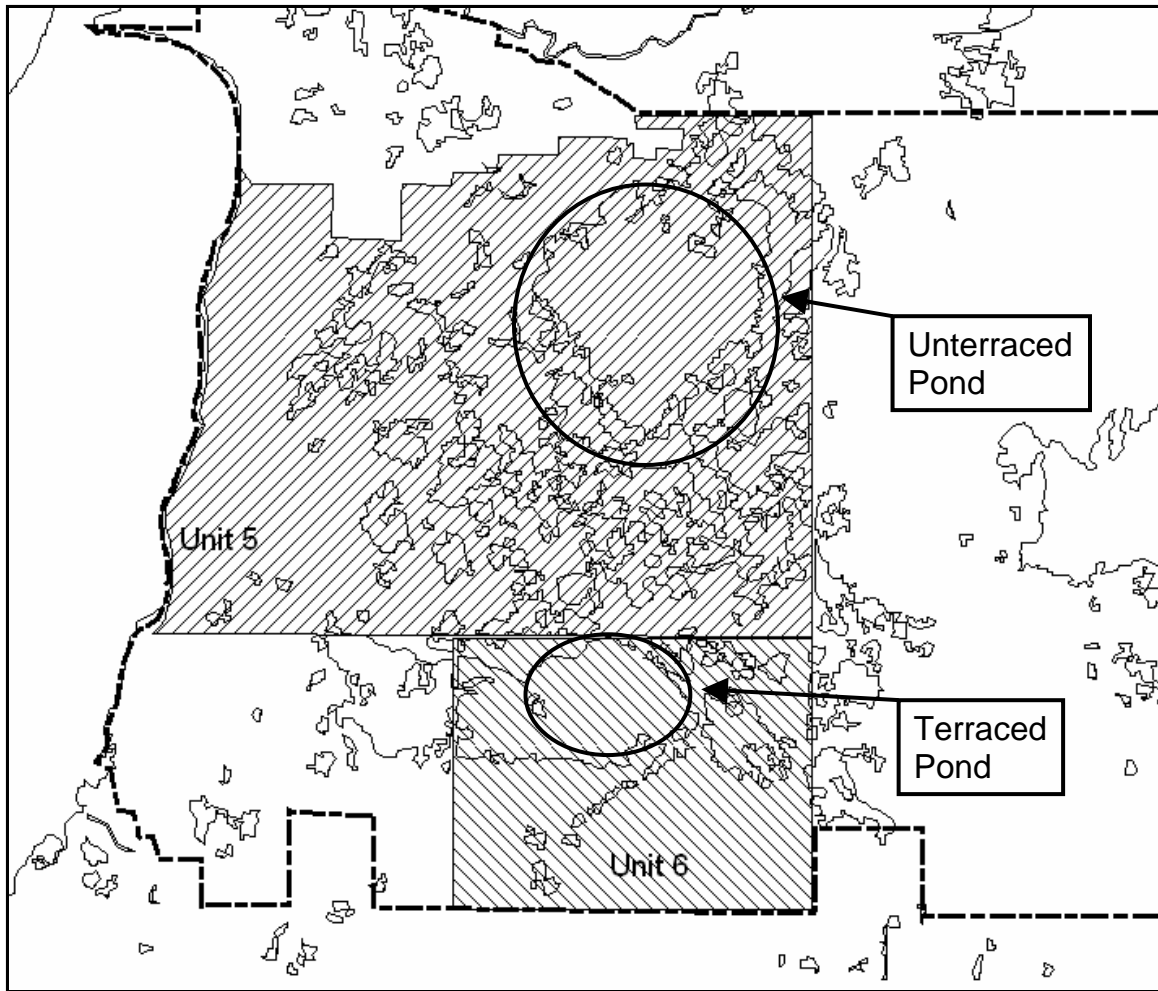


Figure 8. Site 3, Sabine National Wildlife Refuge, Management Units 5 and 6 Terraced and Unterraced Pond Pair

METHODS

Selection of Sampling Points

There were two randomly selected points in each terraced and unterraced pond. Random selection consisted of using Arcview 3.2 (ESRI, Redlands, CA) to overlay a grid on a georeferenced aerial photo of each pond and then using excel to generate random numbers that corresponded to squares within that grid. Once the points were marked in Arcview 3.2 (ESRI, Redlands, CA) the grid coordinates from the geo-referenced map were entered into a Garmin GPS 76 (Garmin Ltd, Salem, OR) which was used to find that point in the pond and mark it with a PVC pole. The random points were then used as the starting point of transects in the two habitat types: near edge and far from edge.

At each point in terraced ponds, transects parallel to the terrace ridges were used to collect core and rake samples. One transect at approximately 1m from the edge of the emergent vegetation on the terrace (hereafter referred to as Terraced Near), and one at the midpoint between that terrace and the nearest parallel terrace, or 50m if terraces were more than 100m apart (hereafter referred to as Terraced Far).

The method used to randomly select sampling locations in the terraced pond also was used to randomly place two points and four transects in the unterraced pond. Two adjacent to the shore (Unterraced Near) and two in the open water at least fifty meters from shore (Unterraced Far). All transects paralleled the closest shoreline.

Pond Characterization

A vial of water was collected upon arrival at each point within a pond to measure turbidity. Water was collected before sampling SAV, from the front of the boat, to minimize the effects of disturbance by the airboat on turbidity. A HI 93703 turbidity

meter (Hanna Instruments, Inc, Woonsocket, RI) was then used to measure the turbidity of the water in the vial. The HI 93703 was calibrated in the lab prior to each field trip. However, during the June 2004 trip the HI 93703 was contaminated with salt water and had to be replaced. In all subsequent trips an Aquafluor Turbidimeter (Turner Designs, Sunnyvale, CA) was used to measure turbidity.

At each transect, whether terraced or unterraced, water temperature, salinity, and conductivity was measured using the YSI 63 (Yellow Springs Instruments Incorporated, Yellow Springs, OH). The sensor was placed into the water over the edge of the airboat near the center of each transect. Water depth was recorded using a meter stick.

At the end of the study a core was taken at each transect to determine soil characteristics. Each soil core was weighed then placed in a 350° furnace to combust organic matter. The remaining mineral matter was used to calculate the percentage of organic matter in the soil.

SAV Abundance

Abundance of SAV was estimated April 2004, June-July 2004, August 2004, October 2004, December 2004, February 2005, and in April 2005 using the rake method (Chabreck and Hoffpauir 1962, Nyman and Chabreck 1996, Hunter 2000, Caldwell 2003), the core method (Gallagher 1974, Ellison et al. 1986, Caldwell 2003), and the 1-m² throw trap (Kanouse 2003, Gossman 2005). The rake method estimated SAV frequency and the core and 1-m² throw trap samples were used to estimate SAV biomass.

Sampling was spread out from June 2004 to July 2004 because of airboat failure. In October 2004 Site 3 was not sampled due to airboat failure. In December 2004 1-m² throw trap samples were not collected because of airboat failure.

I estimated frequency and biomass to account for the variation in SAV over time. Merino (2005) found that frequency estimates were more valuable if SAV was uncommon within a pond and that biomass estimates were more valuable if SAV was common. I collected samples over the course of the entire year because Merino (2005) in her study did not observe two growing seasons as had previously been reported (Joanen and Glasgow 1965).

Rake Eight transects were raked at each site: two Terraced Near (1m from terrace edge), two Terraced Far (transects 50m from, or halfway between terraces), two Unterraced Near (1m from natural marsh edge), and two Unterraced Far (at least 50m from marsh edge in open water).

The rake was a garden rake with the tines painted white. It is used to measure SAV frequency in coastal Louisiana marshes because the water is often too turbid for visual estimations (Chabreck and Hoffpauir 1962, Nyman and Chabreck 1996, Caldwell 2003, Merino et al. 2005). It was touched to the bottom of the pond and lifted thirty times as the airboat idled along transects. Presence or absence of SAV was recorded each time the rake was lifted. If there was SAV on any of the tines, the species present were recorded. Frequency was then estimated using the following formula (Fig. 9).

$\frac{\text{\# times SAV is found on tines after dipping rake}}{\text{\# times rake is touched to the bottom}} = \text{SAV Frequency}$ <p>Example: A rake is touched to the pond bottom 30 times and 12 times it has SAV on the tines. The SAV frequency is 40%.</p>

Figure 9. SAV Frequency Formula

Core Three cores were collected at each transect for a total of 24 per site. Altogether six Terraced Near, six Terraced Far, six Unterraced Near, and six Unterraced Far were collected for each terraced and untterraced pond pair.

Cores were collected with a 10-cm diameter PVC pipe that was open on one end and had a cap on the other end with a small hole in the center. The open end of the pipe was pressed into the upper 20-cm of soil and a rubber plug was inserted into the hole on the other end to create suction. This allowed removal of all the SAV within the water column as well as the upper layer of soil. The sample was presifted in the field through a 2-mm mesh sieve to remove water and small soil particles. Larger pieces of soil were removed by hand and then the SAV and the soil that remained were placed into a numbered Ziploc bag. The samples were kept on ice in the field and refrigerated in the lab to slow decomposition. In the lab, all living plant material retained by a 2-mm sieve was separated by species, weighed, dried in an oven, and reweighed. The dry weight of the SAV and the area of the core were then used to estimate biomass (g/m^2).

1-m² Throw Trap The 1-m² throw trap is a large metal frame one meter on a side and one meter tall. The sides are fitted with netting and the top and bottom are open. This trap was thrown from the airboat. Its primary function was to capture nekton for a concurrent study (Gossman 2005). One throw trap was used for each point at all sites. SAV was removed by hand and placed in numbered Ziploc bags. The samples were kept on ice in the field and refrigerated in the lab to slow decomposition. Samples were separated by species, weighed, dried in an oven, and reweighed. The dry weight and the area of the core were then used to estimate biomass (g/m^2).

Experimental Design

Ponds were the experimental unit for this research. The experimental design was a Randomized Block Design with repeated measures. I blocked by site and sampled every other month. Sampling started in April 2004 and concluded in April 2005.

I tested the assumption that SAV would be more abundant near terraced or natural marsh edge (Appendix A). That test led me to conclude that edge and far habitats differed in untterraced ponds, but not in terraced ponds. I used 10m for edge estimates because edge associated nekton species, which I assumed were correlated to SAV, are found out to that distance (Minello and Rozas 2002).

I used ArcMap (ESRI, Redlands, CA) to determine the percentage of each pond that was edge and open (Fig. 10). For this analysis edge was defined as ten meters from terrace or natural marsh shoreline. In untterraced ponds, the percentages were then used to weight estimates for each sampling technique (i.e. g/m^2 for the cores and 1-m^2 throw trap and % frequency for the rake) based on habitat type (i.e. Terraced Near, Untterraced Near, etc.) because near and far habitats differed in SAV abundance in untterraced ponds. Statistical analysis was then used to determine SAV abundance and frequency at each pond on each of the sampling dates.

Statistical Analysis

Water depth, salinity, temperature, and turbidity were analyzed using the Proc Mixed procedure of SAS statistical software. Proc Mixed is based on a mixed linear model and was used because variance was not homogenous, variation differed by sampling period. The null hypothesis that there was no difference between terraced pond water parameters and the untterraced pond water parameters was tested. Least-squares means for each water quality parameter were then graphed by date using SigmaPlot graphing software. Statistically different means revealed by the graphs were confirmed using a Tukey-Kramer adjusted means comparison test in Proc Mixed (Kramer 1956).

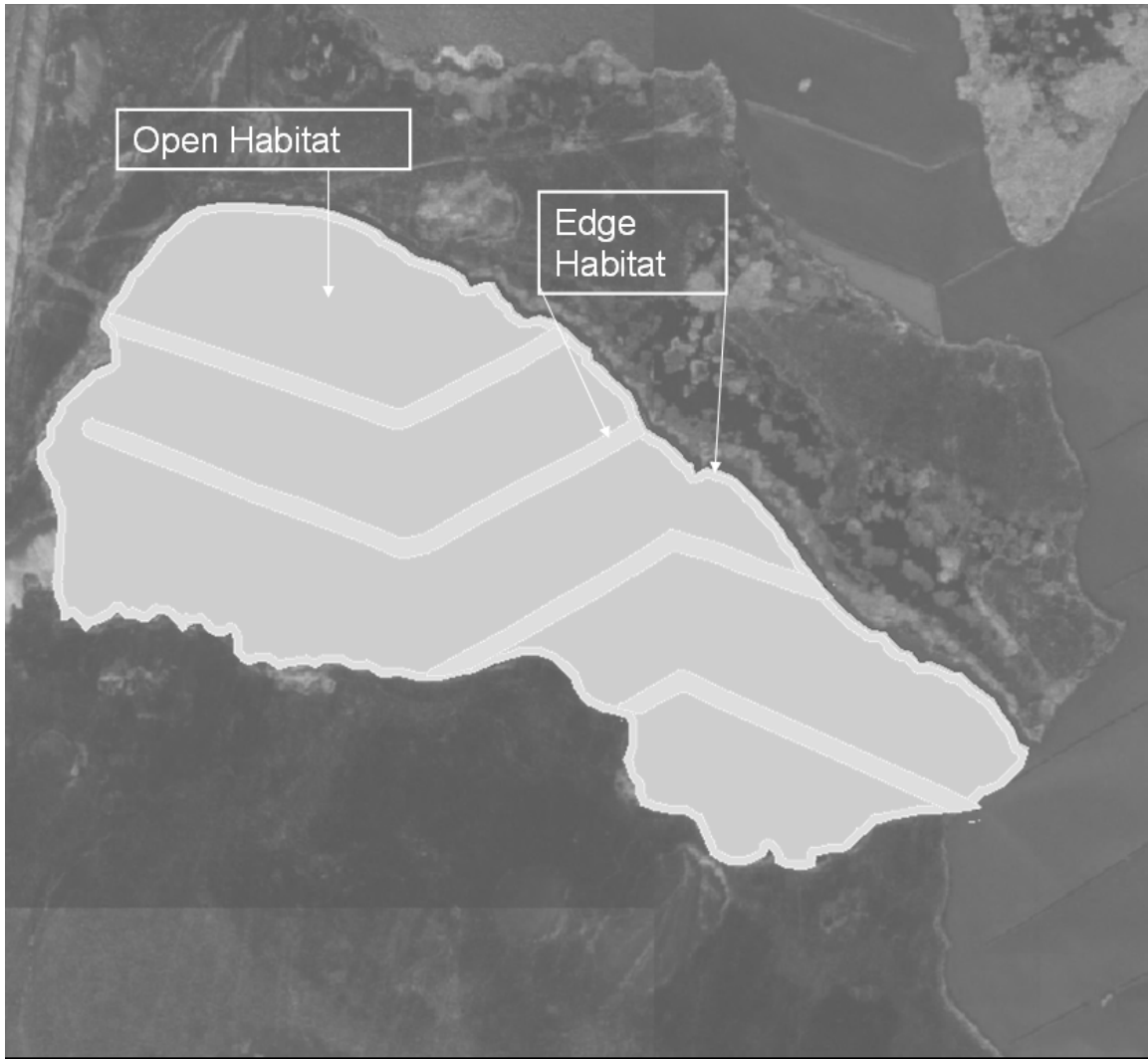


Figure 10. Map of Site One Terraced Pond, Illustrating Habitat Polygons used to Estimate Percentage of Edge and Open Habitat for Weighting SAV Estimates by Habitat Type

Initial analysis indicated that SAV samples did not meet the assumptions of parametric statistics. The residuals were not normally distributed and variances were not homogenous (variance differed between sampling periods). After determining this, the Proc Glimmix procedure of SAS 9.1 (SAS Institute Inc., Cary, NC) statistical software was used to determine the distribution that best fit my data. Proc Glimmix is a general mixed model program that allows the user to fit a model with non-normal distributions. Models for all data had the lowest AIC scores using the lognormal distribution.

Once lognormal was determined to be the distribution that best fit the data, the models were run again using the Proc Mixed procedure after being log transformed. This allowed us to use the distribution suggested by the Proc Glimmix procedure while taking advantage of Proc Mixed procedure's more robust method of handling non-homogenous variance. It allowed us to treat months as a repeated measure and to specify that variance differed for each month. All means presented for SAV are back-transformed from logarithmic distribution with back-transformed standard errors.

Initial analysis (Appendix A) indicated that terraced habitat types did not differ from one another but untterraced habitat types did. Terraced Near and Terraced Far were similar for all three sampling techniques and Untterraced Near and Untterraced Far were dissimilar for all three sampling techniques. Because I had intentionally placed far sampling points further than I assumed edge effects on SAV extended. This was rather surprising. Taking this information into account I pooled my estimates for the terraced ponds rather than weighting them by habitat type.

RESULTS

Pond Characterization

Water depth averaged 43 ± 7 cm in terraced ponds and 43 ± 7 cm in the unterraced ponds. The difference between treatments was not significant ($AIC = 1268.7$, $df = 1$, 2.92 , $p_{\text{water depth}} = .9070$) (Fig. 11). Salinity differed between terraced and unterraced ponds on some dates ($AIC = 519.3$, $df = 6$, 36.6 , $p_{\text{salinity*date}} < .0001$). Salinity was lower in terraced ponds in October (Fig. 12). Water temperature differed significantly between terraced and unterraced ponds and among dates but the interaction was insignificant ($AIC = 761.3$, $df = 1$, 28.8 , $p_{\text{temperature}} = 0.0051$, $df = 6,31$, $p_{\text{date}} < .0001$, $df = 6,32.7$, $p_{\text{temperature*date}} = .5346$, respectively). Water temperature averaged 21.65 ± 1.28 C° in the terraced ponds and 23.723 ± 1.30 C° in the unterraced ponds. The interaction of turbidity and date was significant ($AIC = 917.1$, $df = 6$, 33.5 , $p_{\text{turbidity*date}} = .0003$). Terraced ponds were less turbid in April 2004 and February 2005 (Fig. 14). There was a significant inverse relationship between turbidity and SAV estimates from all three sampling techniques ($p_{\text{rake}} < .0001$, $r = -.399$, $p_{\text{cores}} = .0002$, $r = -.3430$, $p_{\text{throwtrap}} = .0009$, $r = -.309$, $n = 114$). For soil composition, the interaction of treatment (terraced or unterraced) and habitat types (near or far) was significant ($AIC = 1112.8$, $df = 1,144$, $p_{\text{treatment*habitat}} < .0001$). Mean organic matter was $12 \pm 5\%$ for Terraced Near, $21 \pm 5\%$ for Terraced Far, $36 \pm 5\%$ for Unterraced Near, and $25 \pm 5\%$ for Unterraced Far (Fig. 15). Organic Matter was inversely correlated with all three estimation techniques ($p_{\text{rake}} < .0001$, $r = -.364$, $p_{\text{cores}} = .0052$, $r = -.253$, $p_{\text{throwtrap}} < .0001$, $r = -.422$, $n = 114$).

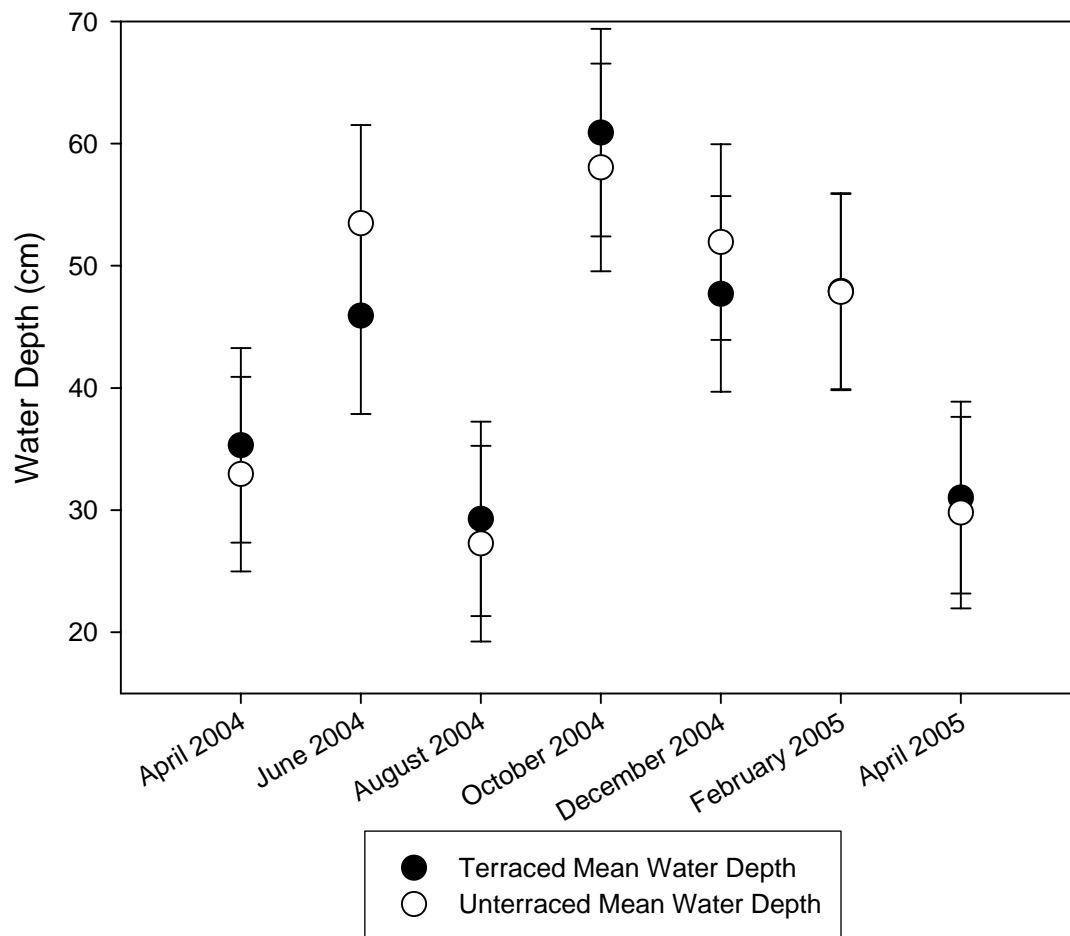


Figure 11. Water Depth of Terraced and Unterraced Ponds by Sampling Date

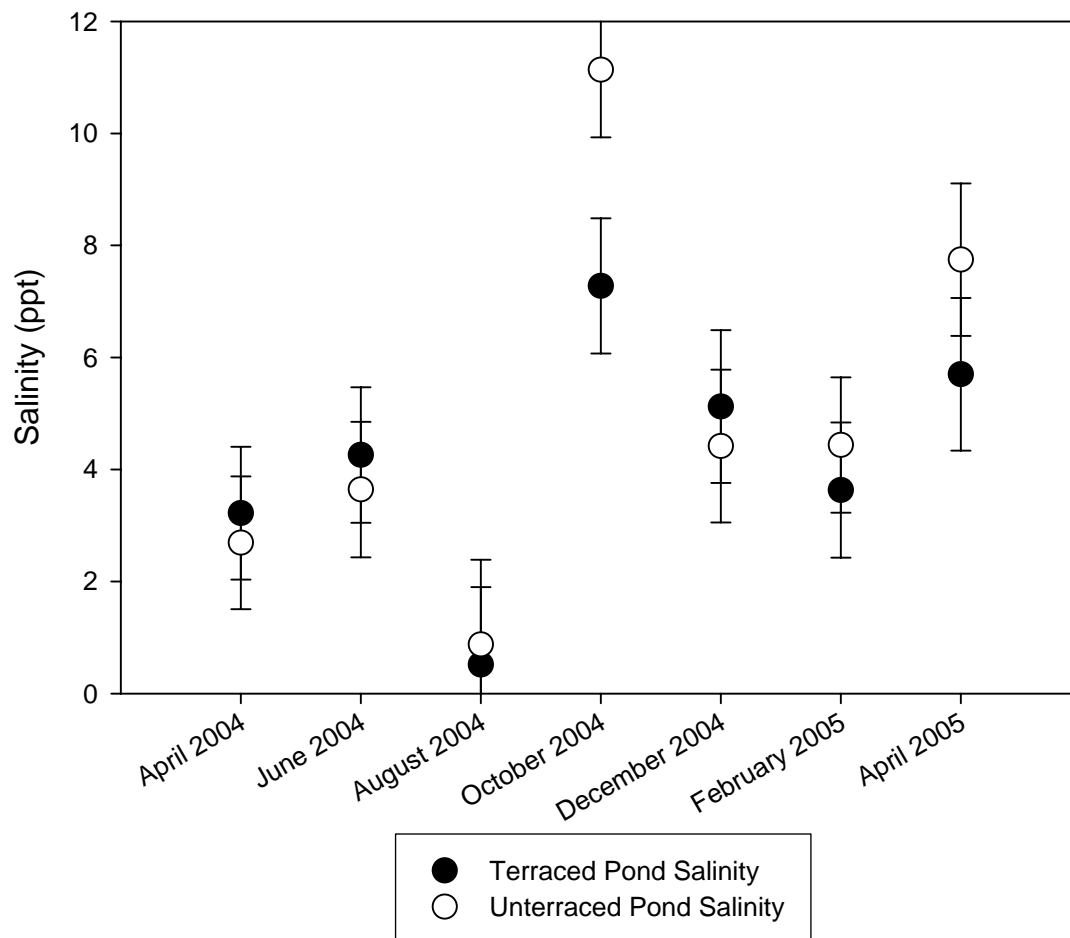


Figure 12 Salinity of Terraced and Unterraced Ponds by Sampling Date

Species Composition

There were 11 species identified during the study and one species that I was unable to identify (Table 2). Eleven were detected by the 1-m² throw trap method, 9 by the core method, and 9 by the rake method. *Ruppia maritima*, *Potamogeton pusillus*, *Myriophyllum spicatum*, and filamentous algae (Chlorophyta) were the four most common species collected.

Rake

The mean frequency of SAV differed significantly between treatments (AIC = 160.5, df = 1, 32.1, $p_{\text{rake}} = 0.0106$, n=40). The mean frequency of SAV for terraced ponds was 20% (SE 13 to 33%) and the mean frequency for untterraced ponds was 9% (SE 5 to 14%) (Fig.16).

Cores

Biomass of SAV differed significantly between terraced and untterraced ponds (AIC = 160.2, df = 1, 31.7, $p_{\text{cores}} = 0.0002$, n=41). The mean biomass for terraced ponds was 5.6 g/m² (SE 3.5 to 8.9 g/m²) and 1.6 g/m² (SE .97 to 2.5 g/m²) for the untterraced ponds (Fig. 17).

1-m² Throw Trap

Biomass of SAV differed significantly between terraced and untterraced ponds (AIC = 144 df = 1, 35 $p_{\text{throwtrap}} = 0.0003$, n=38). The overall mean biomass for terraced ponds is 5.5 g/m² (SE 3.3 to 9.3g/m²) and 1.6 g/m² (SE .94 to 2.6 g/m²) for the untterraced ponds (Fig. 18).

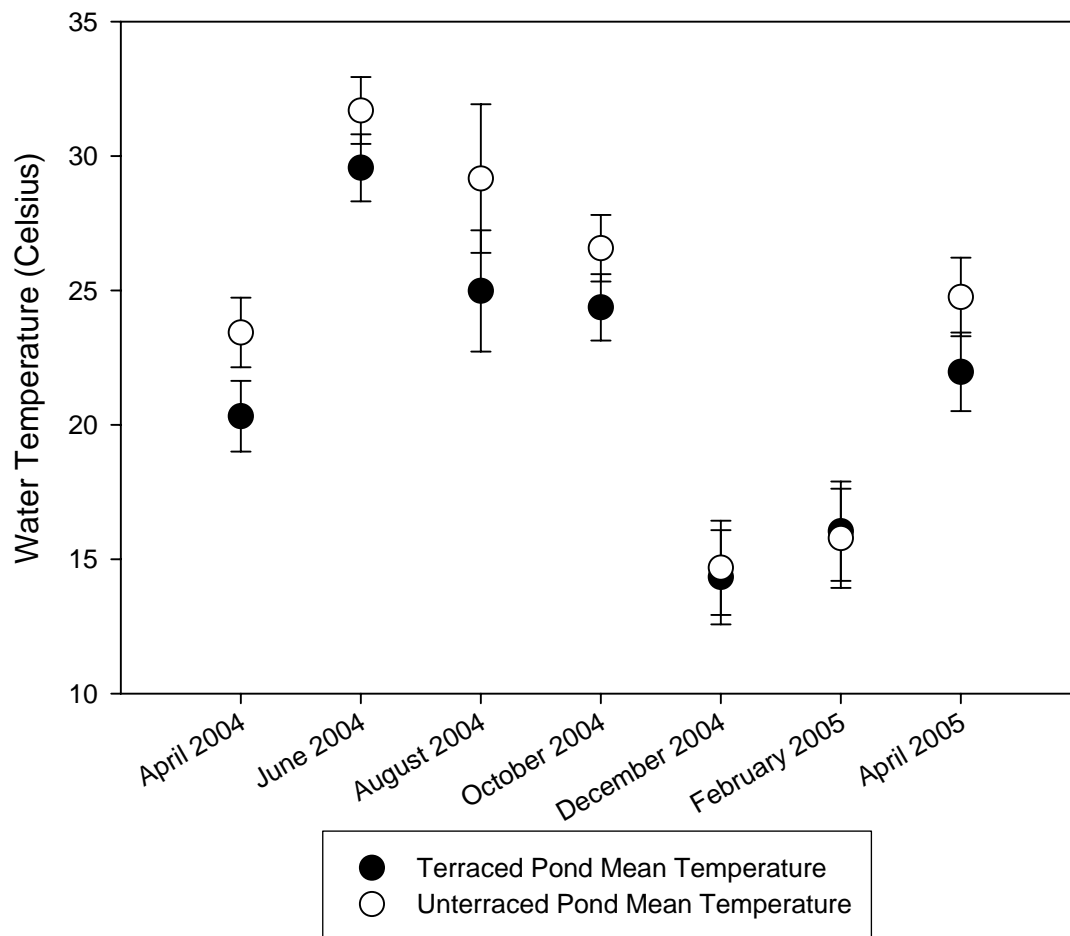


Figure 13. Water Temperature of Terraced and Unterraced Ponds by Sampling Date

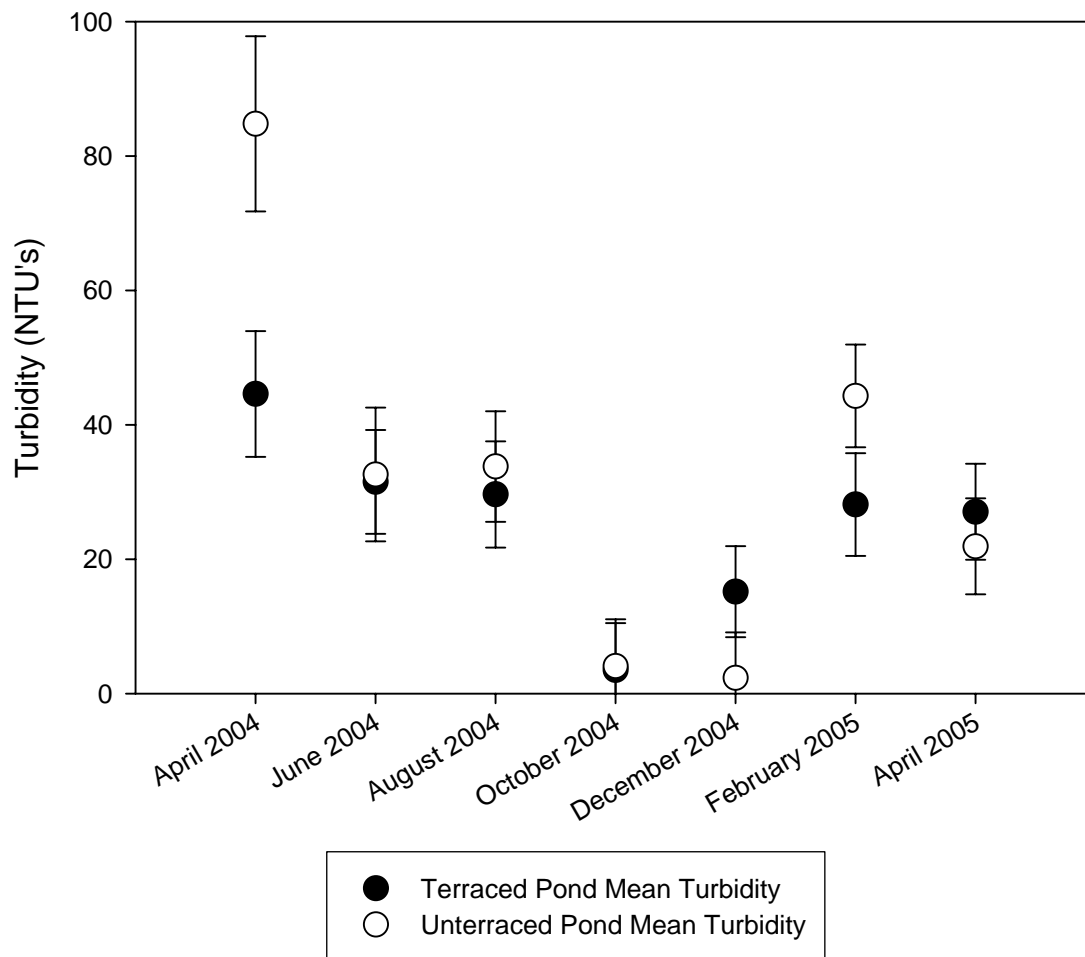


Figure 14. Turbidity of Terraced and Unterraced Ponds by Sampling Date

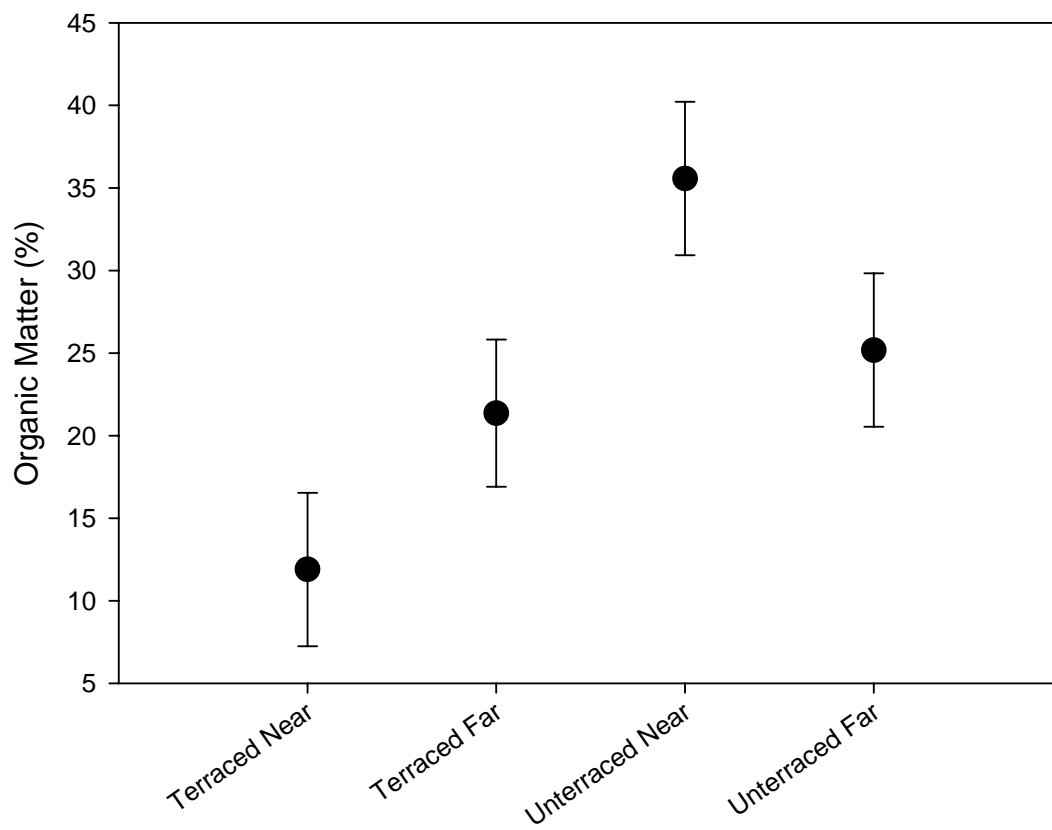


Figure 15. Percent Organic Matter of Pond Bottom Sediments by Habitat Type

Table 2. Species composition of Submerged Aquatic Vegetation as estimated via three techniques in three pairs of brackish marsh ponds in southwest Louisiana averaged over seven sampling dates between April 2004 and April 2005.

Species	NRake Transect.....			NCores.....			N1-m ² Throw Trap.....		
		Frequency	Cover (%)	SD (%)		Frequency	Biomass (g/m ²)	SD		Frequency	Biomass (g/m ²)	SD
unidentified	**	**	**	**	477	1	0.016	0.350	150	4	0.0160	0.3500
Algae	159	72	18	31	477	70	17.849	85.733	150	52	50.3610	278.2193
<i>Ceratophyllum demersum</i>	159	5	<1	1	477	1	0.003	0.058	150	4	0.0360	0.3027
<i>Chara</i> spp.*	159	2	<1	2	477	1	0.000	0.006	150	1	0.0140	0.1715
<i>Echinochloa</i> spp.*	**	**	**	**	477	1	0.013	0.292	150	1	0.0003	0.0033
<i>Eleocharis</i> spp.*	159	1	<1	1	477	**	**	**	150	2	0.1053	1.2737
<i>Myrophyllum spicatum</i>	159	35	15	33	477	73	92.935	294.230	150	30	51.3339	215.9436
<i>Najas guadalupensis</i>	159	16	2	10	477	34	2.508	15.600	150	11	0.5891	6.6995
<i>Nitella</i> spp.*	159	6	<1	<1	477	**	**	**	150	2	0.0000	0.0001
<i>Potamogeton pusillus</i>	159	32	4	14	477	36	3.606	37.558	150	39	1.1541	7.8187
<i>Ruppia maritima</i>	159	42	5	14	477	35	3.689	32.936	150	51	1.1695	8.0602
<i>Vallisneria americana</i>	**	**	**	**	477	1	0.075	1.633	150	3	0.0101	0.1073

* We were unable to identify these specimens beyond Genus

** This species was not detected by this sampling method

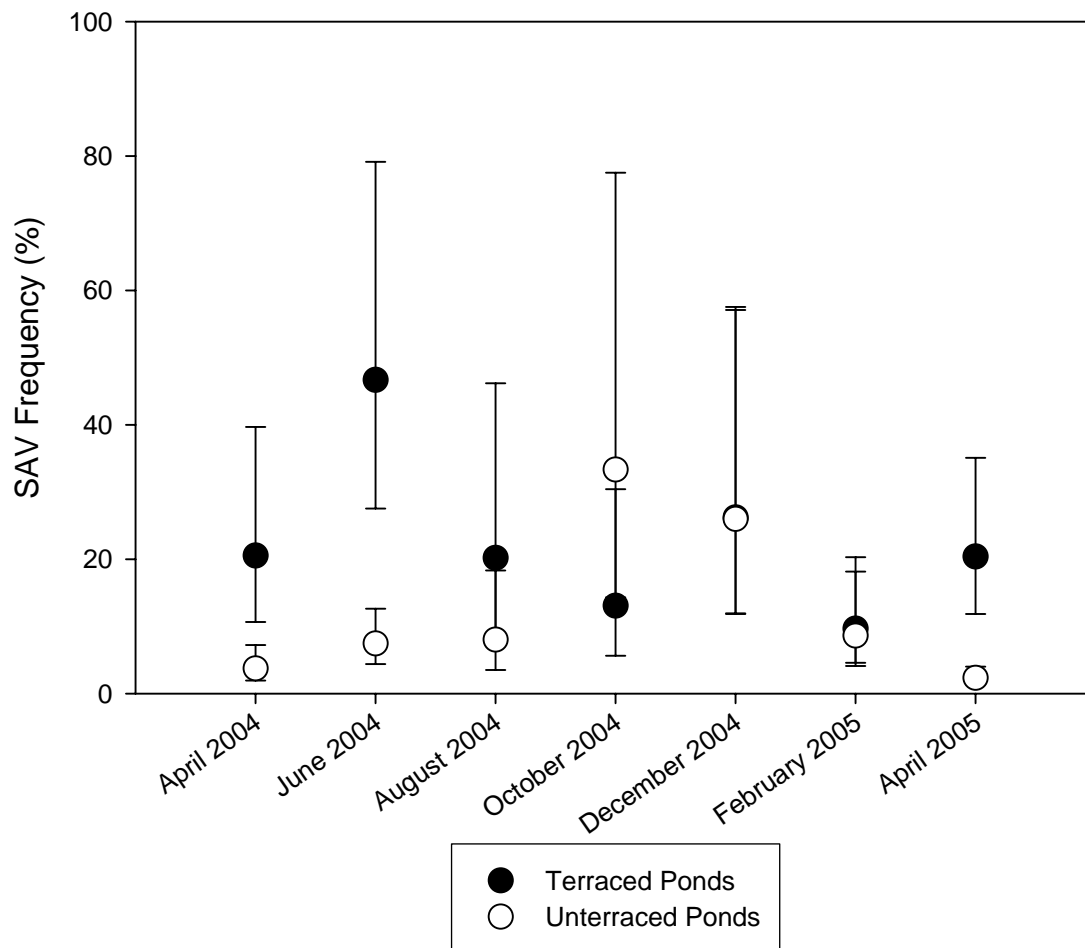


Figure 16. Rake Sampling Technique, SAV Frequency of Terraced and Unterraced Ponds by Sampling Date

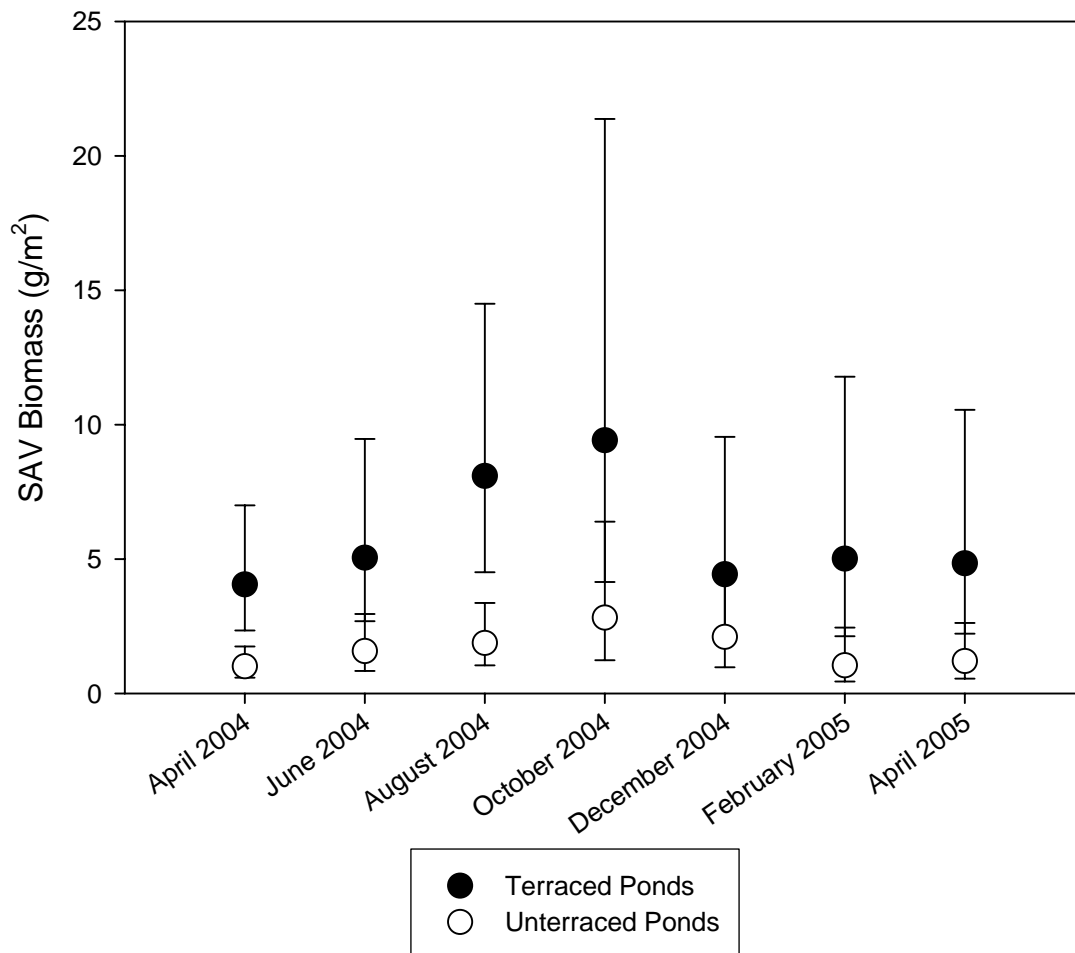


Figure 17 Core Sampling Technique, SAV Biomass of Terraced and Unterraced Ponds by Sampling Date

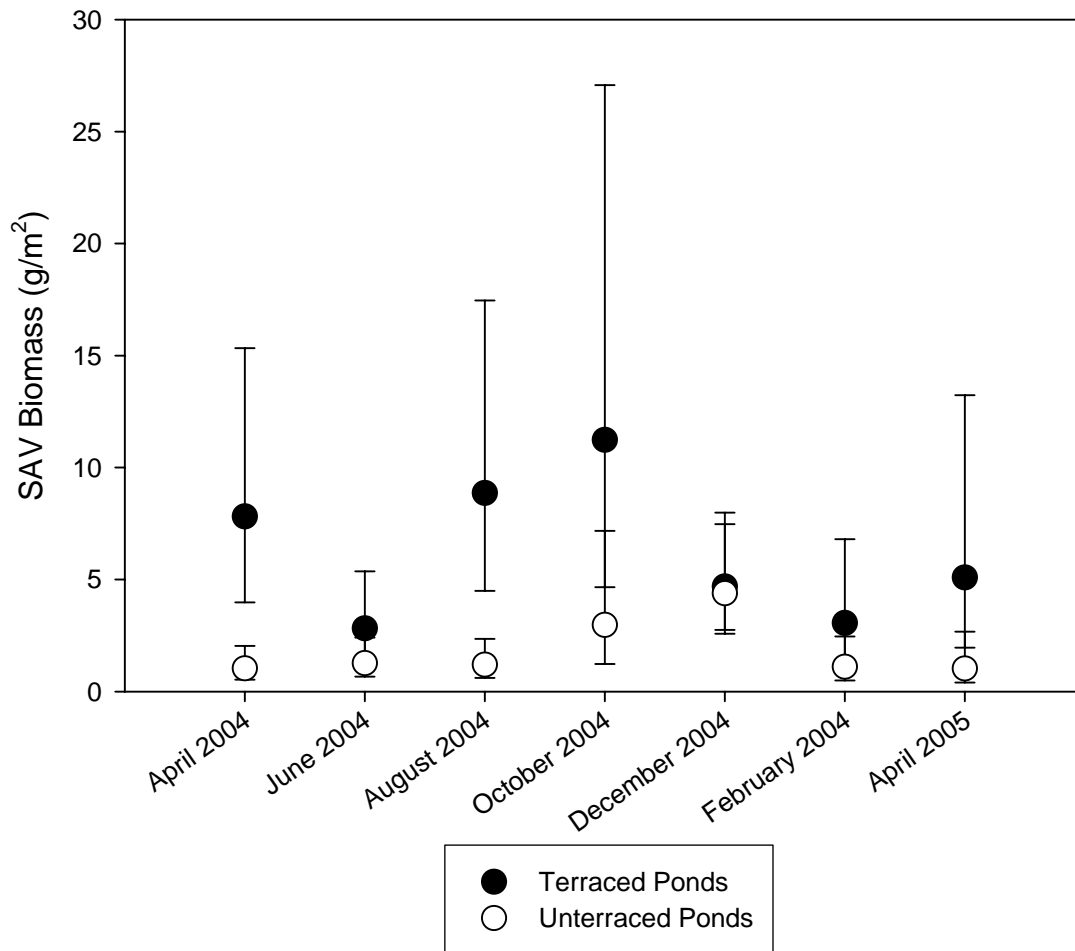


Figure 18. 1-m² Throw Trap Sampling Technique, SAV Biomass of Terraced and Unterraced Ponds by Sampling Date

DISCUSSION

SAV abundance and frequency differed between terraced and unterraced ponds. SAV was found approximately twice as frequently in terraced ponds and terraced ponds had approximately three and half times the SAV biomass of unterraced ponds. It is important to note that the average biomass found in terraced ponds was within the SAV biomass range for ponds in Merino's (2005) study while biomass in unterraced ponds was lower. The average biomass is higher than terraced or unterraced habitat types in Caldwell's (2003) study.

SAV Survey Methods

All three sampling techniques were positively correlated. This indicates that for this study the rake, core, and 1-m² throw trap sampling methods were equal estimators of SAV abundance. These results differ from Merino's (2005) study, possibly because the estimates for SAV were low for unterraced ponds and high for terraced ponds.

Turbidity

It is unclear how terraces increased SAV abundance. *A priori* assumptions that SAV production would be improved by lowered turbidity seems to be partially verified. Turbidity was lower in April 2004 and February 2005 in the terraced ponds. It was also inversely correlated to SAV. These results should be viewed with caution, however. SAV estimates also differed significantly between terraced and unterraced ponds in other months when turbidity did not (Fig. 16, 17, 18). One possible explanation is that turbidity differed sufficiently between ponds on days that I did not sample to affect SAV growth but was not different on the day I sampled. This study was not designed to detect such differences. A new study that incorporates continuously recording turbidity

meters in paired terraced and untterraced ponds could more definitively answer this question. But differences in SAV estimates between ponds could also have been due to other factors, such as organic matter.

Organic Matter

Terraced Near and Terraced Far had soil with significantly less organic matter than Untterraced Near. Terraced Near had significantly less organic matter than either untterraced pond habitat type. High organic matter can inhibit SAV growth and survival (Barko and Smart 1986, Koch 2001). Soils composed of more than 20% organic matter is considered detrimental to SAV because of chemicals such as sulfides produced by bacteria in the anoxic conditions of pond bottoms (Barko and Smart 1986, Koch 2001). This disparity between terraced and untterraced ponds could partly account for the differences in SAV abundance seen in this study. The percentage of organic matter in the soil was inversely correlated with all three estimators of SAV. However, one sampling point had a mean biomass of 68.68 g/m² over the course of the study in soil composed of 44% organic matter. This suggests an alternative mechanism for SAV regulation by organic matter is responsible differences in SAV estimates between terraced and untterraced ponds.

Wave Fetch and Organic Matter Recent studies suggest such an alternative mechanism for SAV regulation by organic matter. Schutten et al. (2004 and 2005) found that in lakes or ponds where wave action was severe or moderate SAV could be uprooted by wave action in organic soils because the sediment shear-strength was insufficient to prevent uprooting. This theory of SAV regulation would help explain how Terraced Far habitat types have higher SAV abundance than Untterraced Far in some months even though both

contain soils with more than 20% organic matter. That is, terraces could be causing the higher SAV biomasses and frequencies in terraced ponds seen in this study by reducing wave energy, thereby preventing SAV uprooting. However, this study did not address wave energy so this would need to be tested in a new study that measures wave energy.

In addition to reducing wave fetch and turbidity, the process of constructing terraces increased the mineral content of soils near terraces. This increased soil mineral matter could also account for some of the differences between terraced and unterraced ponds seen in this study if organic matter regulation by toxic compounds is occurring. If so, this effect should decrease over time as organic matter from emergent matter on the terrace ridges accumulates (Craft et al. 1999). Future terrace studies that take this into account would be an excellent way to test these two theories of SAV regulation by organic matter.

Suggestions for Terrace Construction

Terraces can affect wave action (by reducing fetch) and thereby reduce turbidity also. SAV, distribution and survival however, is affected by a number of other factors as well. Generally these are broken down into light availability factors (which has chemical and biological parameters) and non-light associated factors (which has physical, geological, and geochemical parameters) (Koch 2001).

Terraces can only mediate wave action and turbidity (and then only to an extent determined by the number of terraces and soil type). It is this author's suggestion that factors terraces cannot address be considered prior to terrace construction and that terrace construction be limited to areas where it is appropriate. For example, light availability may be limited by epiphytes and filamentous algae and not turbidity in areas that have

high nutrient inflows (Livingston et al. 1998, Koch 2001). In other areas, water clarity may be sufficient for SAV growth but the soil is too sandy and nutrient poor to promote SAV growth (Koch 2001). In general, restoration planners should avoid building terraces in these areas and focus on reducing nutrient levels and introducing mineral sediment.

The terraces of Site 2 deteriorated and fell apart during this study. The terraces were only four years old then. That deterioration strongly suggests that an evaluation of terraces that have been built to date be conducted to determine the average life span of terraces. However, I also must point out that the terraces of Site 2 were the first terraces designed by Rockefeller Refuge Personnel. The terraces at Site 1 were also designed by Rockefeller Refuge Personnel and were in good condition at the end of the study. Therefore, the terrace deterioration at Site 2 is probably an exception and not indicative of normal terrace longevity. The terraces at Sabine National Wildlife Refuge that Steyer (1993) studied, for example, were still intact over fifteen years after construction (the author is unaware of the terraces' condition post hurricane Rita).

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APPENDIX A: HABITAT-LEVEL ANALYSES

Introduction

This appendix summarizes the initial analysis of SAV data to test the assumption that SAV abundance did not differ between near-edge and far-from-edge habitats, both of which exist in ponds. If this assumption was true, then pond-level estimates of SAV abundance would not need to be weighted to account for amount of near and far habitats. These tests also allowed me to test for effects of terraces that existed near terraces, but were insignificant at the pond level because too few terraces were constructed in a pond. The experimental design called for three sites with paired ponds at each type. Each site was broken into four habitat types: Terraced Near, Terraced Far, Unterraced Near, Unterraced Far. Near samples (Terraced Near and Unterraced Near) represented edge habitat. Far samples (Terraced Far and Unterraced Far) were represented open water habitat. I assumed that terraced edge (Terraced Near) would function better than the open water it replaced (Unterraced Far) but not as well as natural marsh edge (Unterraced Near). I also assumed that the terraced edge would not have an effect on SAV 50m from the terrace. My assumption was based on personal observations of SAV occurrence near natural marsh edge and SAV predictive models which show the same (Lehmann 1998).

Statistical Analysis

Data from all three sampling techniques were analyzed initially using Proc GLM and Proc Univariate of SAS 9.1 (SAS Institute Inc., Cary, NC) but were determined to have non-homogenous variances and nonnormal distribution. Proc Glimmix was then used to determine the distribution that best fit the data. Lognormal distribution was determined to be the best fit. Once that determination was made Proc Mixed was used

after taking the natural log of the data. This allowed utilization of Proc Mixed's more robust handling of non-homogenous variance.

The null hypothesis that there was no difference between different treatment (terraced and unterraced) and distance (near edge and far from edge) combinations were tested. Combinations of interest were Terraced Near, Terraced Far, Unterraced Near (assumed restoration goal), and Unterraced Far (pre-restoration condition). These represented the four habitat types of interest. If significant, the interactions were further analyzed using Tukey-Kramer pairwise comparisons (Kramer 1956).

Results

Rake The interaction of treatment and distance was significant ($p_{\text{treatment}*\text{distance}} < 0.0001$, $n = 159$). SAV frequency for Terraced Near was 15% (SE 7 to 31%), Terraced Far was 19% (SE 9 to 39%), Unterraced Near was 19% (SE 9 to 40%) and Unterraced Far was 4% (SE 2 to 9%) (Fig. 19).

Cores The interaction of habitat, treatment, and sampling date was significant ($p_{\text{treatment}*\text{distance}*\text{date}} = 0.0022$, $n = 477$). SAV biomass for Terraced Near was 3.95 g/m^2 (SE 2.1 to 7.3 g/m^2), Terraced Far was 4.9 g/m^2 (SE 2.7 to 9.2 g/m^2), Unterraced Near was 2.1 g/m^2 (SE 1.1 to 3.9), and Unterraced Far was 1.0 g/m^2 (SE .56 to 1.9 g/m^2) (Fig. 20).

1-m² Throw Trap The interaction of habitat type and treatment was significant ($p_{\text{treatment}*\text{distance}} = 0.0145$, $n = 150$). SAV biomass for Terraced Near was 4.4 g/m^2 (SE 2.5 to 7.8 g/m^2), Terraced Far was 5.1 g/m^2 (SE 2.9 to 9.0), Unterraced Near was 2.1 g/m^2 (SE 1.2 to 3.6 g/m^2), and Unterraced Far was 1.3 g/m^2 (SE .72 to 2.2 g/m^2) (Fig. 21).

Discussion

Estimates from all three sampling techniques indicate SAV abundance and frequencies were similar for Terraced habitat types but differed significantly for Unterraced habitat types. SAV estimates for Unterraced Near were significantly higher than Unterraced Far habitat. Terraced Near and Terraced Far were not significantly different from one another. However, Terraced habitat types were not significantly different from either Unterraced Near or Unterraced Far indicating that functionally they are somewhere between pre-restoration and the restoration goal. However, in the graphs Terraced Near and Terraced Far appear to be functioning as well as or better than Unterraced Near (restoration goal) while in some cases Unterraced Near seems to be no better than Unterraced Far. Although this appears to be the case Tukey-Kramer pairwise comparisons could only confirm that Unterraced Near and Unterraced Far were different. This is likely because the pair-wise comparison test had more degrees of freedom when comparing habitat types within ponds than it did when comparing habitat types between ponds.

These results are similar to my *a priori* assumptions with one exception. Terraced Near and Terraced Far were not significantly different. This indicates that the effects of terraces extend at least 50m and probably further. This was unexpected. Perhaps a future study can determine how far the effect of terraces on SAV does extend.

Based on this analysis I further refined my analysis by weighting the estimates for each habitat type by the percentage of the pond they represented. This allowed terraced pond to untterraced pond comparisons that took into account the additional amount of

edge habitat terraces create and the increased SAV production in the open water habitat of terraced ponds.

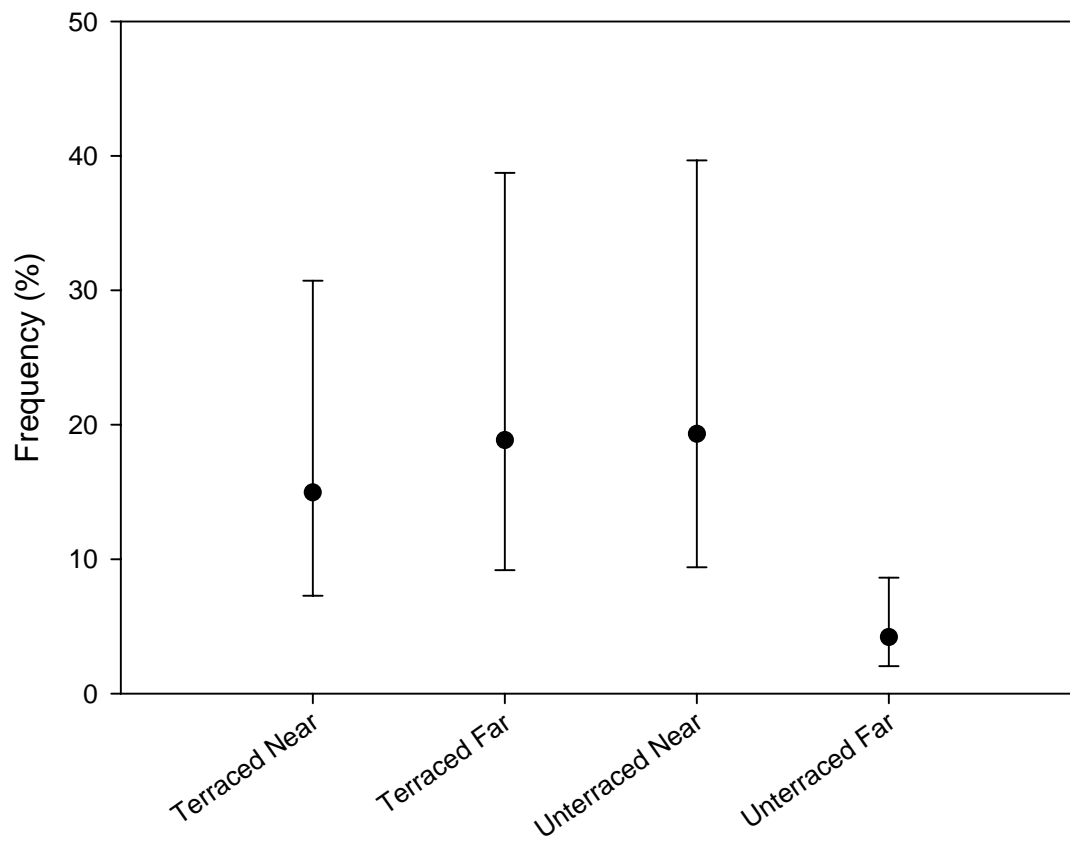


Figure 19. Rake Sampling Technique, SAV Frequency of Terraced and Unterraced Ponds by Habitat Type

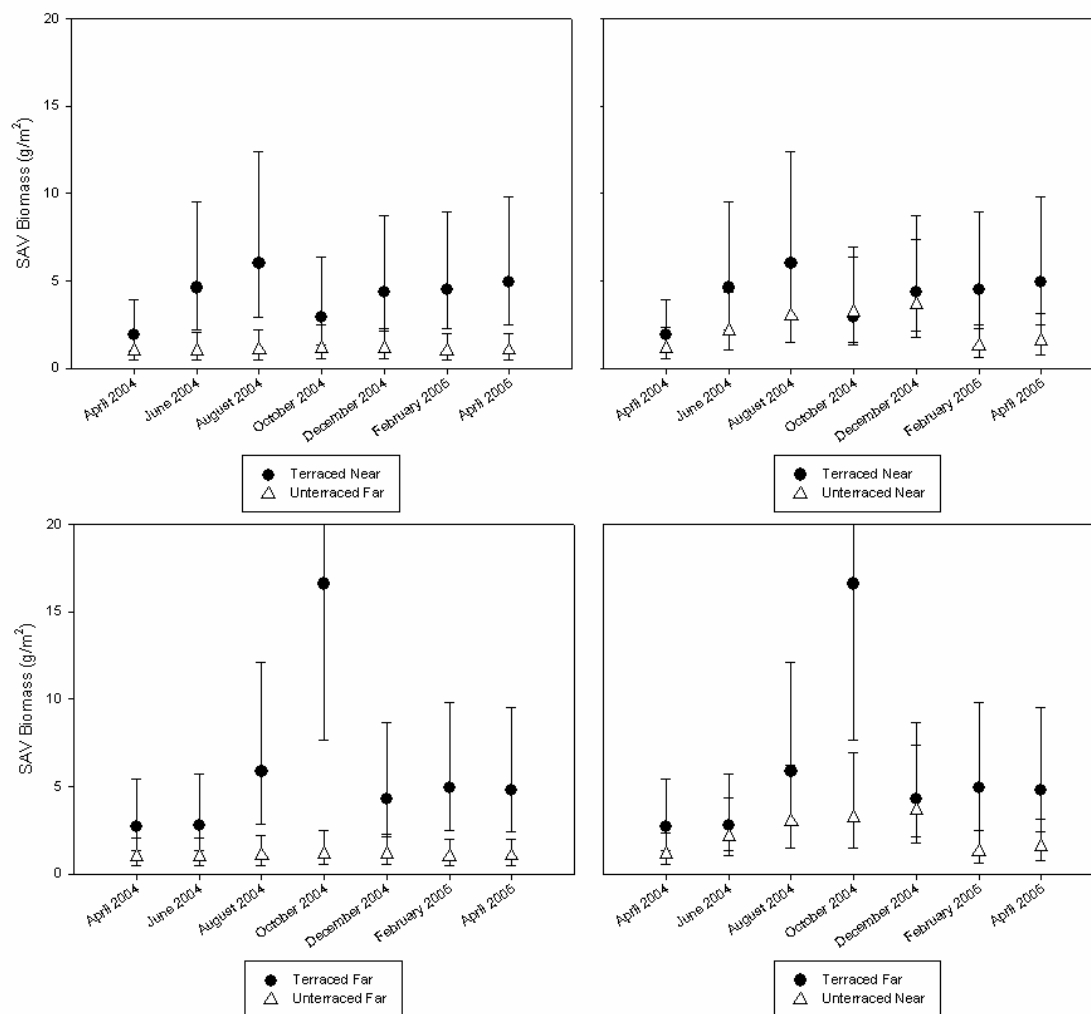


Figure 20. Core Sampling Technique, SAV Biomass of Terraced and Unterraced Ponds by Habitat Type and Sampling Date

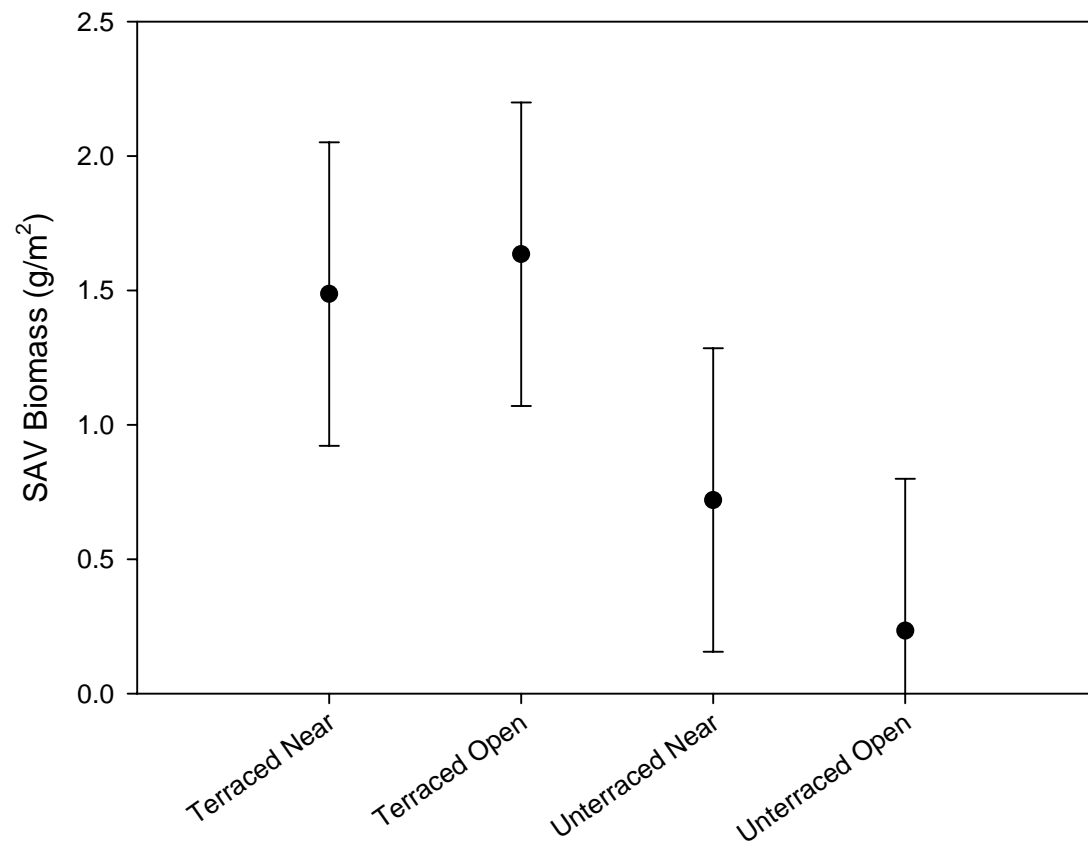


Figure 21. 1-m² Throw Trap Sampling Technique, SAV Biomass of Terraced and Unterraced Ponds by Habitat Type

APPENDIX B: ESTIMATES OF SAV ABUNDANCE FOR WVA MODELS

This appendix includes the arithmetic means of the three estimation techniques with Site 2 excluded and with Site 2 included. Some users of Wetland Value Assessment models (EWG 1998) may prefer estimates of SAV abundance based only upon terraces that existed throughout my study. Those estimates are presented here.

Rake When Site 2 was excluded from the data set, SAV frequency was 67% ($\pm 9\%$, $n = 13$) for terraced ponds and 20% ($\pm 8\%$, $n = 13$) for unterraced ponds. When Site 2 was included, SAV frequency was 45% ($\pm 9\%$, $n = 20$) for terraced ponds and 17% ($\pm 6\%$, $n = 20$) for unterraced ponds.

Cores When Site 2 was excluded from the data set, SAV biomass was 32.7 g/m^2 ($\pm 11.12 \text{ g/m}^2$, $n = 13$) for terraced ponds and 0.52 g/m^2 ($\pm 0.16 \text{ g/m}^2$, $n = 13$) for unterraced ponds. When Site 2 was included, SAV biomass was 21.3 g/m^2 ($\pm 7.97 \text{ g/m}^2$, $n = 20$) for terraced ponds and 0.56 g/m^2 ($\pm 0.14 \text{ g/m}^2$, $n = 20$) for unterraced ponds.

1-m² Throw Trap When Site 2 was excluded from the data set, SAV biomass was 30.7 g/m^2 ($\pm 10.95 \text{ g/m}^2$, $n = 12$) for terraced ponds and 1.08 g/m^2 ($\pm 0.74 \text{ g/m}^2$, $n = 12$) for unterraced ponds. When Site 2 was included, SAV biomass was 19.4 g/m^2 ($\pm 7.65 \text{ g/m}^2$, $n = 19$) for terraced ponds and 0.74 g/m^2 ($\pm 0.47 \text{ g/m}^2$, $n = 19$) for unterraced ponds.

VITA

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In the fall of 2002, Chris left the army and returned to Louisiana to pursue a Master of Science in wildlife at Louisiana State University under the direction of Dr. John Andrew Nyman. Following graduation, Chris will be traveling to Olathe, Kansas, where he will pursue a career in natural resources.